# 1

# Introduction

## 1.1 Information Technology and Healthcare Professionals

The history of modern telemedicine goes back to the traditional telephone about a century ago. Medical advice was given by physicians over the telephone. The term "telemedicine" is very simply a description of supporting medical services through the use of telecommunications. The prefix *tele* comes from the Greek for "distant." So, "telemedicine" literally means providing medical services over distance. Telecommunications used in medical applications can be categorized as sending medical information between a pair of transmitter and receiver. The "medical information" can be as simple as a doctor providing consultation from sophisticated data captured from a human body. "The Radio Doctor," which first appeared in the *Radio News* magazine (*c*.1924), is perhaps the earliest documented case of utilizing telecommunication technology for medical application. Although information technology (IT) has been used in healthcare since then, it was the first scientific literature formally addressing the application of technology in medicine that appeared. (Moore et al. 1975).

IT advances over the past decades mean a wider range of healthcare services can be supported. Indeed, the types of services that can be supported are so vast that any book which makes an attempt to provide comprehensive coverage of all areas will most likely contain thousands of pages over several volumes. This book aims to provide in-depth coverage of how wireless communications and related technologies are used in medical services. We will also look at the challenges and limitations of current technology associated with healthcare information systems.

We begin by taking a look at how simple wireless communication networks function and what a telemedicine system consists of. We look at a number of examples that describe how a primitive system supports healthcare services. Over the course of the book, more sophisticated systems will be described in more detail.

This chapter aims give readers an overview on how IT is widely used in assisting healthcare without going into any technical depth. To begin our discussion, we revisit the term "information technology," something often associated with computer science. Essentially, it is extensively interpreted as a blend of computing and telecommunications. This leads to the acronym ICT, which stands for information and communications technology, also known as "infocomm" for short. All these are merely descriptions of the use of technology to securely and reliably transmit information between two or more entities. IT is widely used in many areas that influence our daily life, for example banking, transportation, manufacturing, etc. This list is seemingly endless. When we see information technologies support so many things that we use on a daily basis, it will not be difficult to understand how widely it can be used in supporting healthcare and medical applications.



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The IT industry has never quite recovered from the "dot-com bubble" bursting in 2000, which saw the industry lose much of its value for several years. And the IT sector was similarly hit by the financial crisis of 2008/09, triggered by the collapse of the subprime mortgage market. Put simply, although IT systems are widely used in many aspects of daily life, the industry remains tied to the global economic market, and so will always be affected by any changes to it. In contrast, health and medical services are two of the few domains that are in consistent high demand, simply because illness is not market led: it is experienced by everyone on the planet to a lesser or greater degree. For this simple reason, healthcare naturally becomes an essential part of daily life that will continue to be in high demand for many years to come.

Having realized the prime importance of healthcare, we go further into how IT is applied to healthcare and medical services. Long before the evolution of IT, herbal medicine practitioners millennia ago were already using the most primitive form of information exchange mechanism, namely communication system, to convey messages on medical services. Wang et al. (1999) documented a case where Shen Nong made use of information exchange for the treatment of respiratory syndrome as far back as 2735 BCE. This may not be the first case but it is certain that medicine and communications have been linked together for over 4000 years. As IT became more sophisticated over time, a more diverse range of medical services could be supported. To name a few, IT in medicine involves drug prescription, spread of pandemic modeling, patient monitoring, remote operation, medical database, and so on. This is by no means an exhaustive list and we cover these as well as many others throughout the book.

Obviously, healthcare professionals can make use of IT advancements in different areas. Advantages brought by IT include improvement in reliability, efficiency, precision, ease of information retrieval, accomplishing tasks remotely, and better organization. Healthcare therefore becomes more readily accessible and more efficient. We will look at how technology benefits healthcare professionals, with the assumption that readers have very little prior IT knowledge and know virtually nothing about the underlying technologies.

## 1.2 Providing Healthcare to Patients

In addition to facilitating medical practitioners perform their tasks, providing healthcare services to patients is also an important issue to address as they are the end users who must feel comfortable to receive the treatment given. Providing a technically feasible solution is not the only obstacle to deal with. Other important issues, including patients' acceptance and accessibility, must also be addressed. We strive to look at providing healthcare solutions to patients using IT from the perspectives of both providers and patients. End users, particularly children and older people, may not be too keen on accepting technology as a tool for healing. Convincing patients of the benefits of IT for healthcare may involve liability, security, and privacy issues. For example, in the case of monitoring or tracking a patient recovering at home, the patient must be assured that personal information is securely kept and no such information accessed in any way without consent.

With the number of senior citizens increasing steadily over the past decade, there has been a growth in demand for healthy aging care (Colby and Ortman 2014). Assistive care provides numerous opportunities for supporting independent living through smart home integration (Bonaccorsi et al. 2015). A comprehensive range of customized solutions for the care of older people has been made possible through advances in IT and digital health.

Before leaving the topic on providing care to older people, it is worth briefly noting the advantages brought to this group of users by telemedicine technology. As population aging is becoming more significant concern in many countries, it can widely be expected that more care and monitoring will be needed. A significant increase in the application of wireless communications in care for older people has been seen over the past few years as related technologies have matured. The cost of service becomes more affordable and portable devices become smaller and more user-friendly. As pervasive computing technology advances, more comprehensive and automated services will become available to the aging population in the years to come (Stanford 2002). The design of interconnected devices and sensors on the patients' side must ensure non-obtrusiveness and can be comfortably worn. Also, users' movement will not be restricted and reliability will not be affected irrespective of wearing condition. User-friendliness is another important design factor, as absolute minimal training should be necessary, especially for children and older people. These should be genuine plug-and-play devices. In this sense, the healthcare system in the patient's home can be installed by a technician during initial deployment. Thereafter, almost everything should be fully automatic, except for unavoidable scheduled maintenance such as battery replacement and calibration.

Let's elaborate more on a patient's point of view as an end user. The primary objective of telemedicine is to provide medical services remotely. Among numerous advantages brought to patients by telemedicine, an obvious convenience is reducing the need for clinical visits. Through the utilization of IT, a patient can rest at home while receiving full medical attention. Reviewing the level of medical support provided over the past two to three decades, it can be seen that IT has certainly provided tremendous benefits to the general public as a whole. The advancement of faster computers and more efficient bandwidth usage has allowed more types of services to be extended to more users. For example, a few decades ago a simple request for medical advice could be obtained by finding a fixed line telephone and dialing in to the clinic where a physician was stationed. With the availability of mobile voice over Internet protocol (VoIP) technology, one can now simply pick up a mobile phone and place a video-enabled call to a physician; the physician does not necessarily have to be situated inside the clinic in order to provide advice. This is just one among numerous examples where IT advancements have made healthcare more readily available. More such examples are presented throughout the book.

While the benefits to patients are obvious, there is a wide range of challenges that different parties face in order to serve patients. These concern people from developers, practitioners, and healthcare management and authorities. The following highlights challenges that different people face, starting from the initial planning stage to the final rollout and continuing maintenance.

From the IT perspective, the fundamental question is feasibility. The primary consideration is whether current technology is capable of doing something. After this comes practicality and cost effectiveness. We begin by considering an example where schoolchildren are to enroll into a program that ensures their school bags are ergonomically prepared so that there will be no issue with back pain. The advantage to participating children is very obvious because the program should ensure that they will not suffer from any back pain. However, how viable is the entire program? We need to understand more about the technology involved in order to answer this seemingly simple question.

In this case study, we have the following parties involved: engineers developing the monitoring system, clinical staff analyzing the captured data, funding bodies providing necessary resources, children participating in the study, and finally participants' parents giving consent to their children's involvement. Below, we look at the case with respect to benefits and concerns from each party's standpoint.

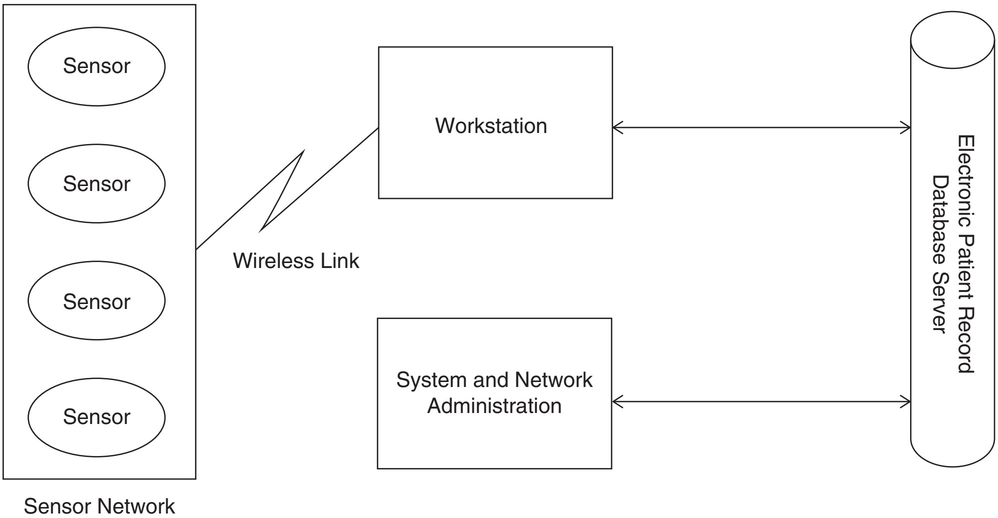


**Figure 1.1** A simple telemedicine system.

### 1.2.1 Technical Perspectives

Biomedical engineers need to develop a system based on requirements specified by clinical staff, such as that illustrated in Figure 1.1, with the necessary sensors and data communication network. This simple system has a number of sensors forming a sensor network for capturing different types of information about a patient. It is linked to the system for analysis by a workstation and storage in an electronic patient record (EPR), and is monitored by the necessary system and network administration tools. In this discussion, we shall not go into the technical details while giving an insight into what is involved. Engineers analyze this by evaluating technical feasibility and practicality. Digging deeper into the technical challenges, one obvious issue to address is how to ensure whatever captured data is meaningful. There are several factors that influence the validity of data, most notably from what the sensors have picked up followed by what has been transmitted and subsequently received. In this respect, the sensors must be securely attached at the relevant points of the participant's body, and each sensor must be sensitive enough to pick up any subtle tilting of the body while not being too sensitive that it picks up any vibration from other sources. Having dealt with these problems, next we must ask whether the sensors are suitable for the specific application – the size may be too large for attaching onto a child, for example – and whether it will cause any discomfort. Are readings affected by any physical obstacles that may be separating the children from the backpack, such as clothing? How is captured data sent out for processing and analysis? Will sensors interfere with each other if placed too close together? These are just some of the questions related to sensors that need to be dealt with.

We shall proceed by assuming that the sensors are well designed and the problems listed above have been overcome. So, we are technically able to capture a set of valid data that tell us something about a child's behavior when carrying a backpack. We now look briefly at how telemedicine is utilized in a biosensor network; we will come back to this with more details in Section 3.5. In the previous paragraph we raise a question about how the captured data is sent out. Essentially, we have two choices: using wireless communications or connecting the sensors with wires. How they compare will depend on the system itself as there is no clear advantage with either option. This is one major topic that we cover throughout this book.

Briefly summarizing the discussion here, we have seen how many questions need to be addressed in relation to the deployment of such supposedly simple health monitoring systems. So, although the system may appear simple enough to patients, its design and implementation may not be as straightforward, and there are many limitations.

### 1.2.2 Healthcare Providers

Healthcare professionals should understand that technology is available for making their routine work easier and safer. Many may still prefer traditional methods, just like many people still prefer jotting down notes using pen and paper. Others may find technologies helpful when using a personal digital assistant (PDA) or tablet computer for the same purpose. There are, of course, many advantages with a tablet, although users may need to familiarize themselves with its user interface. Another concern to some is the risk of losing its stored data due to breakdown, or unauthorized access of data if backed up on a cloud server. We can see that people who are used to conventional ways of carrying out a task may need to be convinced of the associated benefits technologies bring, in order to impel them into learning to utilize these technologies. So, as a practitioner, a simple-to-use interface would be a fundamental design requirement. User experience (UX) developers should involve professionals throughout the design process. The entire process should be as automated as possible while maintaining a very high level of reliability. Different applications may have very different demands. For example, telesurgery requires ultra-high precision for control and crystal clear imaging details with no time delay, whereas teleconsultation may have much less stringent requirements.

Although technical advancements have made, and will continue to make, current technologies more efficient and fault-free, and hence do and will enable numerous tasks to be accomplished quicker and more reliably, the incentive to use them may not be compelling unless practitioners actually know how to use them. Getting used to something new, especially for critical tasks, can be a major challenge. A uniform change to new technology for all applications would be vitally important for a swift switch to make good use of the new technology.

### 1.2.3 End Users

The end users of the system are the patients. The term “patient” refers to someone who receives medical treatment or a medical service, which includes routine check-ups. We should clarify at this point that by definition a person described as a patient may not necessarily be unwell. A perfectly healthy person can be referred to as a patient in this regard. Here, in our case study we have a group of patients who participate in the study of schoolbags on children. They help with the study by having a set of sensors attached to their back while carrying a schoolbag of varying weights. An illustration on how the sensors are attached to the back of a patient is shown in Figure 1.2. We discuss the case study from a patient’s point of view by first looking at Figure 1.2. As shown, a number of sensors are attached to the back; each sensor is connected to a data capturing device by a wire. Movement is somewhat affected by the wires so we can readily see the advantages of using wireless sensors as far as the patient is concerned. So, why not wireless? This example exhibits three major technical challenges that make wires extremely difficult to eliminate. First, sensors attached to a child’s back must be very small. Powering the sensors can be an issue as installing an internal battery may be a problem. Also, wave propagation issues effectively rule out its use between the body and the bag, as absorption would be a very significant issue. Finally, measurement accuracy given the physical separation of individual sensors and the amount of movement would make a

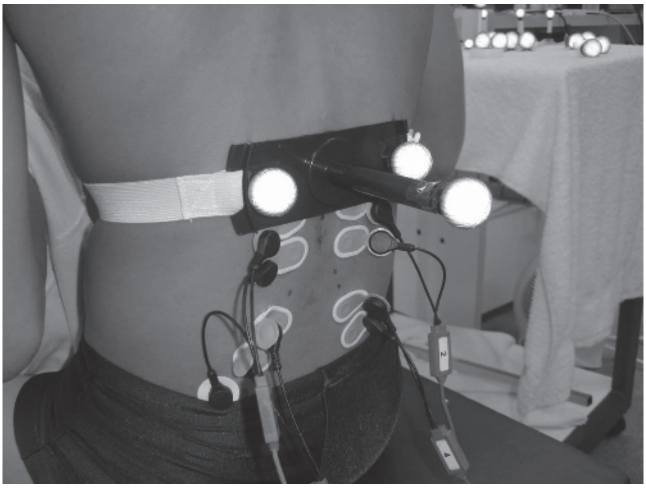

**Figure 1.2** Sensors attached to the back of a patient using wires that severely restrict the patient's movement.

wireless solution impractical. For all these reasons, patients have to bear with the wires surrounding them while participating in the experiment.

### 1.2.4 Authorities

Funding agencies and authorities are most concerned about cost effectiveness. Long-term benefits to the community must be clear. In this particular case study, obtaining funding may be difficult despite all the benefits stated in the above subsections. This is primarily due to the projected time length of realizing the benefits; this will only be seen when a clear statistical trend of reduction in back pain is attained. The political details are far beyond the scope of the book so we will not discuss anything in detail here. As a general rule, those looking to acquire funding for projects on applying technology to healthcare services, by and large, need to prove that the benefits will be immediately realized. And this explains why there is generally a lack of financial support for healthcare solutions using innovative technology.

## 1.3 Healthcare Informatics Developments

In this section, we look briefly at how healthcare and bioinformatics have evolved over the past decades. Medical science has undergone consistent advancements for thousands of years and IT is certainly a much newer topic that has only really commenced from the first computer by Konrad Zuse (1936). Soon after the birth of computers, information storage devices were born. Health informatics is made possible only when computers are connected together to form a network, hence computer networking. The whole idea of health informatics kicked off after World War II as technology became more readily accessible. These networks provided a framework to link hospitals together in the cyberworld. More recently, computational intelligence has made a wide range of services available. In fact, by combining with multimedia and technological advancements, healthcare has been enhanced greatly. As illustrated in Figure 1.3, a diverse range of medical and healthcare services can be supported by technology.

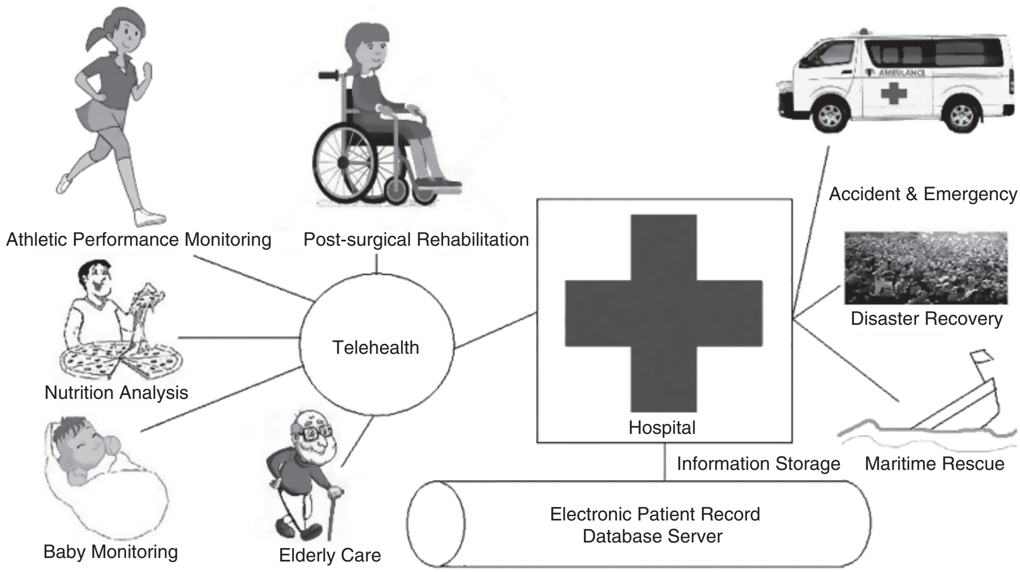


**Figure 1.3** Some examples of digital health applications supported by telemedicine.

So, the eight decades since *The Radio Doctor* appeared have seen the blend of technology with medicine in just about all areas of practice. We have very briefly covered how health informatics has evolved from the first computer; we shall pay more attention to more recent developments that are directly related to possible future developments. The first challenge that many people will talk about are probably security and privacy issues. There are cases of patient information being leaked because of a wide range of reasons from breach of security to simply loss of storage devices. A significant part of health informatics involves ensuring the security of data keeping. This includes protection from theft or altering of information and policies in ensuring that data will not be misused by parties authorized to access patient records. A thorough discussion on security and privacy is presented in Chapter 6. In addition to assurance for safeguarding medical data and privacy, there are many other issues to address since health informatics entails a very wide range of topics in linking people, resources, and devices together, and many of these have developed independently over time. The first documented case of modern healthcare informatics deployment in the United States was around the 1950s in a dental project pioneered by Robert Ledley for the National Bureau of Standards (now the National Institute of Standards and Technology) (Ledley and Wilson 1965). More medical information systems were developed over the next few years across the USA and most projects were advanced independently of each other. It was therefore practically impossible to develop standards for health informatics systems. The International Medical Informatics Association (IMIA) was formed in 1967 with the main objective to coordinate the development of health informatics and related technological advancements. Soon after its formation came the programming language MUMPS (Massachusetts General Hospital Utility Multi-Programming System) for building healthcare applications which is still used today in electronic health record systems. There was soon a need for different variants of the programming languages to run on different computer platforms and a standard was inaugurated in 1974. It is now developed as "Caché" for medical application development on different computer platforms. It is worth noting that, although Caché is still currently used today, many present electronic health record systems are developed using relational databases.

The traffic flow in terms of passengers and cargo internationally has seen substantial growth. partly because of the synergistic effect between the lower cost of air travel with an influx of budget airlines and global e-commerce (Bigne et al. 2018). This has facilitated the flow of emerging pathogenic microbes across countries (To et al. 2015). The increasing international travel of passengers and animal products can rapidly import emerging or re-emerging infections into a region and export them to other parts of the world. The huge population and density of metropolitan cities, in particular, provide an ideal incubator for brewing and spreading new infectious agents and antimicrobial resistance. Thus this growing issue of infectious diseases and control of emerging and re-emerging microbes should be controlled and monitored through the development of international health informatics strategies.

So, a quick look at the development of healthcare informatics reveals that a vast collection of topics in IT are involved. It deals with all aspects of technologies related to preventive caring, consultation, treatment, rehabilitation, and monitoring. From this point onwards, we shall concentrate our discussion on communications and networking technologies for healthcare. Related technologies will also be covered from time to time as appropriate.

## 1.4 Different Definitions of Telemedicine

Telemedicine, the combination of ICT, multimedia, and computer networking technologies to deliver and support a wide range of medicine applications and services, has several widely accepted definitions. The definition given in *wiki* is: “Telemedicine is a rapidly developing application of clinical medicine where medical information is transferred through the phone or the Internet and sometimes other networks for the purpose of consulting, and sometimes remote medical procedures or examinations.” This definition is simply a brief recapitulation of what is described in Section 1.5 below. Other definitions exist. For example, the Telemedicine Information Exchange (Brown 2005) gives its own definition as the “the use of electronic signals to transfer medical data from one site to another via the Internet, telephones, personal computers, satellites, or videoconferencing equipment in order to improve access to health care”; and (Reid 1996) defines telemedicine as “the use of advanced telecommunications technologies to exchange health information and provide health care services across geographic, time, social, and cultural barriers.”

Variations of definitions do not stop here. The Telemedicine Report to Congress (Kantor and Irving 1997 gives “telemedicine can mean access to health care where little had been available before. In emergency cases, this access can mean the difference between life and death. In particular, in those cases where fast medical response time and specialty care are needed, telemedicine availability can be critical. For example, a specialist at a North Carolina University Hospital was able to diagnose a rural patient’s hairline spinal fracture at a distance, using telemedicine video imaging. The patient’s life was saved because treatment was done on-site without physically transporting the patient to the specialist who was located a great distance away.”

Among these various definitions, there are several points in common, including that they were all given in the mid-1990s and are closely related to providing different kinds of medical services over distance by utilizing some form of telecommunication technology.

We mention what telemedicine is at the beginning of the book. Very briefly, it is about the use of telecommunications and networking technologies for the transmission of information related to medical and healthcare application. In modern telecommunications, information can be transmitted across many types of networks in many forms. By definition, telemedicine can be as simple as

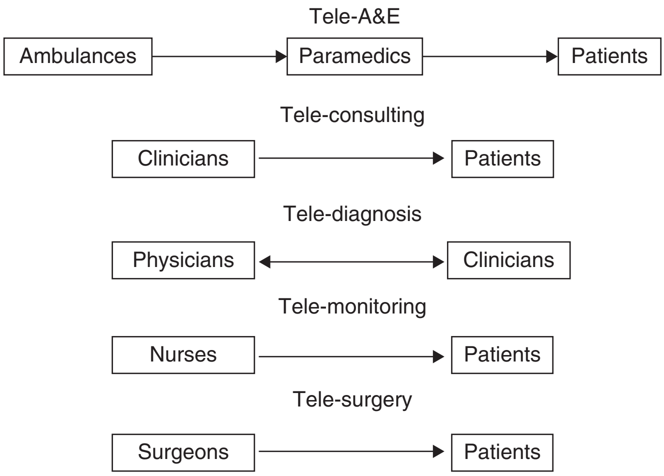


**Figure 1.4** Subsets of telemedicine connecting patients to medical professionals.

two doctors talking about a patient over the telephone or as complex as a sophisticated global hospital enterprise network that supports real-time remote surgical operations with surgeons situated in different parts of the world controlling an operation that takes place in one hospital simultaneously. To elaborate on the vast coverage of telemedicine, Figure 1.4 summarizes a number of services that telemedicine is capable of supporting. It is not a complete list of all services that telemedicine is capable of supporting while showing all major services currently used worldwide. As we begin looking at these services, it is not difficult to see that there is one thing in common: conveying medical information from one entity to another. Before we proceed further, remember this is an introductory chapter so don't worry about the technical terms and details, as we shall cover them thoroughly throughout the book. Obviously, each application entails different types of information. We look at each of these examples and see what telemedicine does. A simple application like teleconsultation involves the delivery of advice, often verbally from an expert to people in need of medical information. In recent years this has extended to services using mobile devices. Telediagnosis lets experts carry out diagnostics with medical instruments from a remote location, quite simply by providing a communication link between the two locations. Telemedicine can be far more complex than this, like sophisticated tele-A&E (accident and emergency) services that can involve high resolution digital images along with vital signs of a patient collected in a remote location that must be transferred to the hospital with maximum reliability and minimum delay. Some systems may provide additional features such as video conferencing functions and the real-time retrieval of medical history records. Likewise, telemonitoring facilitates monitoring of patients recovering at home or moving around in locations away from the hospital by transmitting different types of data. Depending on the specific application, remote patient monitoring may involve the attachment of small wireless biosensors on a patient forming a body area network (BAN), where data captured by individual sensor is collected within the BAN before being sent collectively for subsequent processing. In this kind of situation, a telemedicine system may include different types of communication networks. While we cover networking in more depth in Chapter 2 with specific emphasis on the following telemedicine applications in Section 2.4, we refer to the example in Figure 1.5 to get some understanding of how three separate networks are interconnected to form a telemedicine system. Here, the patient under observation is surrounded by a BAN which the patient carries when moving around. Captured data captured is sent to a nearby local area network (LAN) that stores and

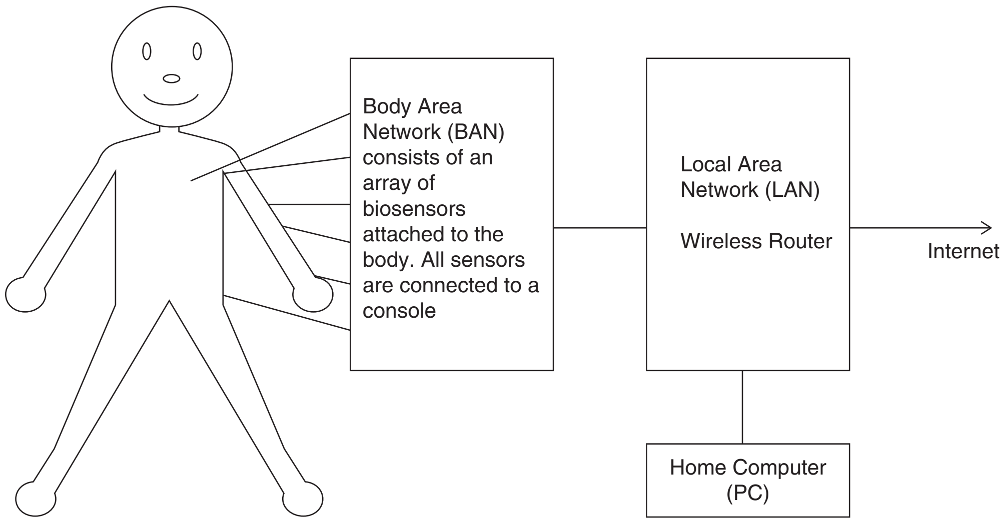


**Figure 1.5** Simple network connection from the patient's body to the outside world for a wide range of digital health services from general health assessment to remote diagnosis and disease management.

processes the data. The LAN effectively serves as a bridge between the hospital that is served by the metropolitan area network (MAN) and the patient's home. The LAN is very simply an ordinary home network that is permanently installed at the patient's home. Through installation of appropriate equipment associated with the BAN and establishing a connection to the hospital via the MAN, a telemedicine system that performs telemonitoring can be set up.

Telesurgery is probably the most convoluted application, partially because of the precision involved. In order to perform a surgical operation from a remote location, apparatus must have a very high degree of movement in all directions and an unobstructed view must be delivered to the surgeon with good clarity. Therefore, the following basic requirements must be fulfilled to perform even a simple operation:

- Sensors capable of capturing the slightest movement of a surgeon's hand in real time with extreme precision.
- Cameras that can deliver incredibly sharp images of the patient without any obstruction. This is particularly challenging as movement of surgical tools must be taken into consideration. Maintaining a good view of the patient at all times is vitally important.
- Actuators that exactly replicate three-dimensional hand movements as interpreted by the sensors with no time delay.
- A communication network that is fast enough to deliver all types of data in both directions, and reliable enough to ensure that it is free of transmission errors throughout the entire operation.

By now we should be convinced that telemedicine entails technologies far more than simply POTS (plain old telephone system) that allow two medical professionals to share information verbally. In the later chapters we look at more telemedicine applications and the underlying technologies that make telemedicine possible. In particular, we will take a close look at how artificial intelligence (AI) and augmented reality (AR) change the way telerobotic surgery is changing how a surgeon practices.

Connecting people and resources together for better healthcare covers more than the examples given above. We have described ways that the general public can directly benefit from telemedicine;

there are other applications, such as connecting relevant authorities worldwide to track the spread of diseases in epidemiological surveillance, that had been found to be effective in limiting the crisis caused by severe acute respiratory syndrome (SARS) and avian influenza (bird flu) over the past decade and the Zika virus in more recent years (Chan et al. 2016). Another less obvious yet important application in safeguarding the community is telepsychiatry where psychiatrists are able to monitor acutely anxious patients so as to proactively prevent violent crimes using telemedicine.

Telemedicine covers almost all aspects of daily life. For example, we can easily access healthcare information by the touch of a 4G LTE cellular phone; getting nutrition information for a healthy diet while dining out has never be easier. Throughout the book we will see telemedicine virtually support all aspects of healthcare in daily life for consumers with a portable device such as a smartphone, tablet, or notebook computer.

## 1.5 The Growth of E-health to M-health

We all know what the Internet is, and almost certainly we access the Internet on a daily basis. It is widely understood that the Internet allows email access, video conferencing, information retrieval from websites, contents downloading of music, video clips, pictures, etc. The evolution of the Internet provides information sharing with worldwide coverage. In essence, long sequences of binary bits 1s and 0s are carried across the world, trillions of them a second. Although only two possible states are sent in the digital world, combinations of these can represent virtually anything that one can imagine. The Internet is about integrating devices and information together. In the cyberworld information can travel across any part of the world in a fraction of a second. To get a better understanding of how advances of Internet technology support telemedicine we must first look at the Internet's development from its birth and what it offers telemedicine.

### 1.5.1 Evolving from the Internet

The origin of the Internet was likely the Galactic Network documented by (Licklider and Clark 1962). We can see that telemedicine has a far longer history than the Internet yet the impact of the growth of the Internet on advances in telemedicine is very significant. This includes connecting computers and devices together, along with the development of packet switching (Kleinrock 1961), and the eventual evolution of networks capable of carrying different types of data to be delivered across a single transmission medium. With such a capability, communication networks can support telemedicine in many areas, such as:

- Reliability: quality of service (QoS) assurance
- Information sharing: medical web pages online
- Audio: teleconsultation, respiratory, cardiac, and pulmonary sounds
- Still images: X-ray, scans, medical images
- Video images: teleconferencing, telepsychiatry, medical education
- Databases: electronics patient records, e-pharmacy, alternative medicine
- Vital signs: electrocardiography (ECG), electroencephalography (EEG) analysis, and storage.

The Internet, in its early days, supported primitive services such as BBS (Bulletin Board System) and email. These were fairly adequate for teleconsultation services. It was not until 1984 that the Internet incorporated TCP/IP (transmission control protocol and the Internet protocol), which supports multimedia data traffic.

Today's "modern" Internet, which supports all types of telemedicine services described above, has not removed all of the various challenges that need to be considered (or dealt with) in the continued development of telemedicine. Interestingly, a computer virus that spreads across the Internet may in certain aspects replicate epidemiological control that we touch on in the previous section. A computer virus is defined as a program that interferes with a computer's normal operation. There are many ways viruses can spread across the Internet. Very commonly, they are transmitted as email attachments. Viruses can be disguised in various forms as embedded in other programs or files such as pictures and video clips. They can also be concealed in illicit software just like a human carrying hepatitis virus who looks healthy from the outside. It is well known that antivirus utilities can be installed on a computer to safeguard it from virus attacks. Telemedicine can actually do something similar in preventing bacterial and viral infections and spreading by proactively tracking down the pattern of the spread as well as the mutation of viruses using signal processing techniques.

### 1.5.2 Digital Health on the Move

The development of wireless communications technology allows more flexible deployment of telemedicine for supporting off-site applications. More recently, with the advancements of related technologies such as batteries and antennas, wearable devices have been made widely available for many medical and consumer healthcare applications. These open up numerous opportunities to new telemedicine services in providing treatment and preventive care as data can reach almost anywhere while the patient is on the move. Further, internal memory can store the collected data offline so that the monitoring device does not even have to stay connected at all times to support continuous health monitoring.

Now we have seen a few examples of different telemedicine application types that use the Internet, we need to ask what is really needed for supporting telemedicine. Unlocking the potentials of what telemedicine can offer entails a thorough understanding of various technologies, from ICT to medicine. The Internet does appear to support unlimited data flowing to virtually anywhere in the world. Of course, this perception is not exactly correct. The Internet, or storage facilities, can become saturated when too much data is dumped onto it. Further, processing requirement to extract relevant information from a large dataset also poses challenges to computational resources.

A good example of such limitation is revealed when we used to be pleased with the video quality that DVD brought to us before the turn of the millennium, this was soon followed by the HD (high definition, 720p where "p" stands for progressive scan) and FHD (full high definition at 1080p). The 4K ultra high-definition (UHD) format has been commercially available for several years and we are moving into the 8K era that is expected to be launched in time for the 2020 Tokyo Olympic Games (Miki et al. 2015). From the video's point of view the picture resolution gets better all the time while each iteration requires higher data throughput, more data storage, more efficient algorithm for data compression, and subsequent decompression. It is not difficult to understand why as of 2019 an affordable 4K UHD TV is readily available yet finding a good selection of 4K videos is not as easy. What we see in the video market here is that the amount of information that we can receive practically and economically can be limited by one or two of many factors that yield quality enhancement. In the same context, it is theoretically possible to monitor a wide range of health parameters of a patient continuously. What we need to consider is what relevant data is useful for helping the patient; how accurate is the useful data; how difficult it is to maintain the desired precision; how often is a reading taken; and how long does it take to capture, analyze, transmit, and store the useful data. So, the key point here is that we need to understand the limitation of what we collect and how we handle the data.

### 1.5.3 Data is Sent as a Sequence of "Packets"

For a start, telemedicine is about healthcare across the entire world. It does not necessarily mean all medical knowledge should be made available there. Flooding the networks with information will cause it to slow down and malfunction, eventually causing data loss. The Internet must be used in a responsible way since it is a shared medium. Minimizing overheads is therefore an important task for telemedicine system developers. Determining what kind of information should be sent requires an understanding of data composition. Data is sent across the Internet as "packets," a packet is a unit of binary bits sent from the source to the destination. Figure 1.6 illustrates a simplified structure of a typical data packet that is sent across the Internet (Mullins 2001). It shows that only a portion of the packet contains the actual information that needs to be delivered. The remaining bits are "overheads" that facilitate the transmission of information. Very similar to sending a letter through the postal system, we put the piece of paper that contains our actual message into an envelope, and the envelope contains basic information like the sender's address (source location), destination address (recipient location), airmail label (delivery method), and postage stamp (class of service). The protocol defines the delivery method, and the type of service marks the class of service. Finally, we also have the actual information. In addition, checksum is used for checking data integrity upon receipt, and additional services similar to registered or courier post are also available in the digital networking world. Certain communication protocols provide guarantees for successful delivery, and different QoS schemes can be set to prioritize data traffic across the network.

So we see that a data packet contains far more than the actual information. However, we need to bear in mind that we cannot change the way data is structured as it is necessary to comply with applicable standards for data transmitting across the Internet (both IPv4 and IPv6). What we need to do is to ensure that telemedicine services, especially when utilizing the Internet, should incur minimal overheads. We revisit the topic of transmission efficiency shortly in the next chapter. In summary, what we have seen in this section is that the growth of the Internet provides us with a platform for popularizing telemedicine services with more sophisticated applications possible. There is a need of ensuring that what is sent across the Internet is carefully chosen.

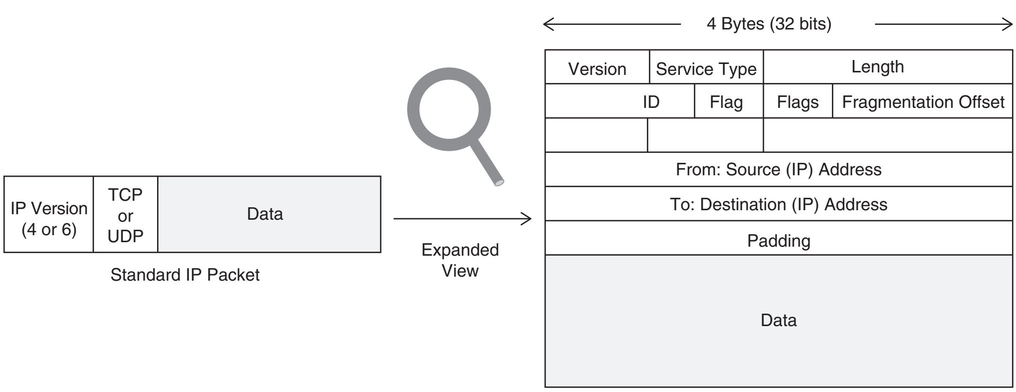


**Figure 1.6** Simplified structure of a typical data packet that contains the actual health-related information along with redundancies such as origin/destination address, timing, and additional data checking codes.

## 1.6 The Connected World Between Human and Devices

Devices and machines are manufactured to work for people. The concept of the Internet of things (IoT) links "things" together via the Internet with a high degree of mobility (Sun and Ansari 2016). "Things cover basically everything connected together like sensors, devices, systems, consumerables, patients, medical, and technology professionals, etc. IoT is about connectivity and processing that provides a platform for telemedicine system to connect patients with their surrounding environment and digital health records, all readily available to their caregivers. Common consumer electronics devices such as smartphones and smartwatches can be wirelessly linked to a wide range of sensors and to an IoT network to acquire comprehensive health information about a patient, including physiological information, daily activities, environment, and potential hazards. Integration of patients and devices through the IoT can support decision making for treatment and recommendations for preventive care.

IoT is a key driver of digital health transformation across the medical industry. Low cost components such as sensors and radio frequency identification (RFID) tags are used in vast quantities in healthcare management of both patients and inventory (Manzoor 2018). Recent advances in IoT provide new opportunities in customized health management, assistive home care, smart pills, and medication management systems.

"Fog" computing is an emerging technology that distributes the load of processing toward to the edge of the network (Fan and Ansari 2018). The main advantages of using fog computing include minimizing latency (the delay of data transfer), network bandwidth conservation (efficiency), and optimal data processing with better analysis and insights patient state of health, all made possible through IoT integration.

Before leaving this introductory chapter, we should briefly return to data security. As the Internet is a shared medium, we should be reminded of the risk of security breach, as anyone can access the Internet. Telemedicine demands the highest standard of data security, both in terms of information accuracy and patient privacy. This is covered in Chapter 6.

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